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Advanced Renewable Energy Storage

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Advanced Renewable Energy Storage is the final report for the Victor Valley Wastewater Reclamation Authority Renewable Energy Storage and Recycled Water project (Contract Number: EPC-15-079) conducted by the University of California, Riverside. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact ERDD@energy ca gov.

ABSTRACT

The Victor Valley Wastewater Reclamation Authority intended to develop an energy management system that uses an experimental energy management controller (smart controller) coupled with an innovative battery storage technology (flow battery) and improve power quality to increase recycled water generation. The energy management system would stop violations of the California Public Utilities Commission’s Rule 21 governing interconnection and minimum import agreements. These agreements require that the generators must continuously import power from the utility and cannot supply 100 percent of the energy and power for the wastewater treatment plant from its own on-site biogas generation. Violations of the minimum import agreement reduce the production of renewable energy on-site and was thought to result in poor power quality shut down of the site’s recycled water equipment. The energy management system was designed to use Primus Power flow batteries, which would better control electric power load to and from the grid. Primus Power was only able to deliver two of the eight flow batteries it had committed, and thus the full energy management system was not completed for the project. Although the energy management system as originally conceived could not be constructed and tested, other components of the system were built. The smart controller was constructed and programmed. A foundation for the flow batteries was created and its ability to command the batteries was evaluated with the two delivered batteries. Although not tied to the energy management system, the project resulted in collaboration with Southern California Edison to make improvements to power quality and prompted a new interconnection agreement that eliminated minimum import requirements. These events freed the Victor Valley Wastewater Reclamation Authority to increase its renewable energy generation and production of recycled water.

Keywords: Rule 21 Minimum Import Interconnection Agreement, renewable energy, Title 22 recycled water, energy management system, flow battery, controller, power quality

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EXECUTIVE SUMMARY

Background

Victor Valley Wastewater Reclamation Authority (VVWRA) owns and operates a wastewater treatment plant in Victorville, California that serves a 279-square mile area that includes Apple Valley, Hesperia, Victorville, Spring Valley Lake, and Oro Grande and treats about 10.7 million gallons of wastewater a day. The plant has facilities that produce recycled water and renewable energy.

VVWRA generates recycled water to meet California Code of Regulations Title 22 standards, that is repurposed for multiple uses. The recycled water is generated using an ultraviolet light treatment system that is one of the largest consumers of energy at the wastewater treatment plant and is very sensitive to changes in power quality. Electricity from Southern California Edison, the local utility, powers the ultraviolet system, and when small fluctuations occur in the power quality, the ultraviolet system shuts down. These small fluctuations in grid power quality, commonly known as blackouts or brownouts, are called "quality events." Quality events and their resulting shut down of the ultraviolet system require at least one hour to reset and return to producing recycled water.

VVWRA also generates renewable energy at its wastewater treatment plant. To treat wastewater, VVWRA uses anaerobic digestion, which creates digester gas, a renewable fuel. The digester gas is used to fuel two 800-kilowatt generators that generate renewable energy and have the potential to supply 100 percent of the energy and power for the wastewater treatment plant.

The generators are interconnected with the utility through California Public Utilities Commission's Rule 21 Interconnection. The specific type of agreement that the utility made available to VVWRA at the time the generators were installed, following the guidelines of the California Public Utilities Commission, is a minimum import agreement. Minimum import agreements require that the generators do not supply 100 percent of the energy and power for the wastewater treatment plant and that wastewater treatment plants continuously import power from the utility. If the wastewater treatment plant violates the minimum amount of import power (minimum import) for more than two seconds, the generators are taken off-line, and the utility supplies 100 percent of the energy and power required for the wastewater treatment plant until the generators are brought back on-line.

A violation of the minimum import occurs when the amount of power generated gets too close to the amount of power being consumed. Avoiding minimum import violations requires a continuous balance between the amount of power produced and the amount of power consumed. This balance is difficult to achieve at the wastewater treatment plant because the amount of power the wastewater treatment plant consumes changes faster than the output of the generators, and the plant's power consumption also decreases faster than the generators can ramp down.

A violation of the minimum import stops the production of renewable energy until the generators are brought back on-line, which can take one to four hours. From correlation, it appeared that minimum import violations also generated quality events that caused the ultraviolet system to shut down.

Shutdowns also cause significant increases in the workload of staff in multiple departments to conduct a collaborative response to the event. All systems and corresponding equipment, instrumentation, and programmable logic controllers (PLCs) must be reset and verified.

Project Purpose

The purpose of the project was to design and build an energy management system to reduce the number of minimum import violations and therefore reduce the frequency of ultraviolet system and generators shutdowns. Reducing the frequency of shutdowns would increase the amount of recycled water and renewable energy the VVWRA could produce.

This project intended to develop an energy management system that uses an experimental energy management controller (smart controller) designed for use in the solar power generation sector coupled with an innovative battery storage technology (flow battery). The energy management system would compensate for different rates at which energy consumption and energy generation occur at the wastewater treatment plant. The compensation would be achieved by storing energy in the flow battery that would otherwise cause a violation of the minimum import. The stored energy could then be released when wastewater treatment plant energy consumption increases at a rate higher than the generators can respond to. The energy management system would also save money on utility power costs and reduce the wear and tear on equipment caused by shutdowns.

The goals of the project were to: (1) help California reduce the consumption of potable water; (2) demonstrate a pre-commercial, integrated energy management and control system that will result in both energy and water savings; and (3) implement a cost-competitive system that water treatment facilities throughout California can use when implementing their own water- and energy-saving systems.

Project Approach

The approach to the project initially was a seven-step process.

1. Investigate the operational characteristics of the components involved in the energy management system and derive a mechanism to interact.
2. Investigate the details of minimum import violations that had occurred in the past.
    a. Evaluate corresponding operational conditions
    b. Determine time scale of the import violations and generators off-line
3. Develop smart controller logic.
4. Test the logic in simulation.
5. Install the energy management system including the flow batteries, smart controller, and balance of plant.
6. Field test the energy management system.
7. Tune and optimize the energy management system.

The approach had to be modified based on three developments: the elimination of minimum import; discovery that the majority of quality events were not in fact caused by minimum import violations, but rather, were a function of the utility's power quality issues; and Primus Power's inability to deliver the promised flow batteries.

The elimination of minimum import requirement required a new agreement that gave the researchers more freedom. Removing the threat of minimum import violations and equipment shutdowns enabled the researchers to be more aggressive and work with the energy management system to tune and optimize management of the balance between power consumption and power generation.

The second development arose from the investigation into the details of minimum import violations that had occurred in the past. Researchers found that most of the quality events that caused the ultraviolet system to shut down were not caused by minimum import violations, but rather, by fluctuations in power quality from the utility, independent of the generators and the power produced. Researchers further found that the quality events had characteristics that could not be resolved with the energy management system, the generators, or wastewater treatment plant operations. Although these characteristics diminished the ability of the emergency management system to reduce the number of shutdowns the ultraviolet system and the generators experienced, the project retained its objective to use the energy management system to evaluate the performance of the flow batteries and the smart controller's ability to manage the power profile at the wastewater treatment plant.

The third development was devastating. Primus Power was having financial difficulties and could deliver only two of the promised eight flow batteries. Two flow batteries do not have enough capacity to create an energy management system and manage the power profile. The only thing that could be tested was the ability to control the flow batteries and evaluate their performance.

Project Results

Although the energy management system as originally conceived could not be constructed and tested, other components of the system were built. The smart controller was constructed and programmed. A foundation for the flow batteries was created. The inverters were installed, and the smart controller was interconnected through a power energy management system to the inverters and flow batteries. The logic in the smart controller was tested in simulations, received some optimization, and fared well in the simulations. Finally, the smart controller was connected to flow batteries, and its ability to command the batteries was evaluated.

Although not tied to the energy management system as planned, the project did achieve its ultimate goals to reduce shutdowns of the ultraviolet system and the generators, generate increased levels of recycled water, and generate increased levels of renewable energy. Researchers met with engineers from the utility to discuss the investigation's discovery that most shutdowns were a function of the utility's power quality issues and not of minimum import violations, prompting the utility to adjust the infrastructure, which significantly improved the power quality and reduced the number of quality events from 96 in 2016 to fewer than 30 in 2019, a reduction of nearly 70 percent. This reduction corresponded to fewer shutdowns of the ultraviolet system and the generators, which, in turn, corresponded to increased production of recycled water and renewable energy.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

Partnering with the University of California at Riverside Center for Environmental Research and Technology provided opportunities for Biogas Engineering, the Victor Valley Wastewater Reclamation Authority, and UC Riverside researchers to present the project at three conferences, a symposium, and a workshop.

The anticipated target audiences for the technology are municipalities and private industries that use self-generation. The proposed technology would have been applicable to all industrial facilities with self-generation that operate under no-export or net import agreements with utilities.

The near-term markets for the technology are municipalities with self-generation. After the technology has been successfully demonstrated on multiple projects, the private sector with goals of reducing long-term energy costs, will begin to experiment with the technology. The long-term market will be residential and small businesses that have self-generation.

Benefits to California

The project shed light on the positive effect that increased attention to quality events can have on power quality in specific areas. VVWRA had been dealing with quality events and the disturbances they cause for years. During the summer it was common to have multiple events in a single day. The quality events were, in fact, the main reason for trying to develop an energy management system at the facility.

Although VVWRA and the utility previously had considerable communication and had collaborated on multiple energy projects to resolve efficiency and power outage issues, it was not until this project investigated power quality as part of its research that the issues were resolved. The significant reduction of variable power quality and the resulting system shutdowns increased production of recycled water and renewable energy in the area and saved money on utility costs

In addition, the utility's new interconnection agreement prompted by this project's research enables VVWRA to export and produce more renewable energy. When renewable energy generators were first installed at the WWTP, exporting power to the grid was not allowed for the project. However, recent changes to requirements for participation in export interconnection agreements allow this export. Every increase in the production of renewable energy brings California closer to satisfying its climate change goals.

CHAPTER 1: Introduction

This project was designed to help California simultaneously address two state concerns: water conservation and climate change.

Background

The Victor Valley Wastewater Reclamation Authority (VVWRA) wastewater treatment plant (WWTP) generates both recycled water and renewable energy. Both recycled water production and renewable energy generation require significant volumes of consistent, quality power, and both systems are sensitive to small fluctuations in power. The VVWRA has long been plagued by power quality fluctuations, known as "quality events," that temporarily shut down the production of recycled water and generation of renewable energy. In 2016 quality events occurred 96 times, each time causing both the production of recycled water and the generation of renewable energy to shut down. In 2017, the plant experienced more than 100 quality events. These power disturbances not only disrupt the recycled water and renewable energy systems, they affect the entire wastewater treatment plant operation and increase the load on the power grid.

The goal for this project was to create an energy management system (EMS) that would mitigate power quality fluctuations and thus increase the amounts of recycled water produced and of renewable energy generated in service of California's climate change goal.

Producing Recycled Water

The VVWRA produces recycled water using an ultraviolet (UV) light treatment system that is one of the largest consumers of power at the plant, requiring approximately 500 kilowatts (kW) to power banks of UV light bulbs that sanitize the water to California's Title 22 standard. Electricity from Southern California Edison, the local utility, powers the ultraviolet system. "UV disinfection uses powerful UV lights to disinfect the wastewater and traditionally is one of VVWRA's biggest energy users." Under existing conditions, quality events interrupt the UV system, resulting in effluent exceeding California's strict Title 22 recycled water requirements and requiring VVWRA to dispose of the water without beneficial use, routing it to infiltration ponds. VVWRA calculated that these quality events have resulted in wasting a total of 2.5 million gallons per year. The UV requires a minimum of one hour to reset, during which time the facility cannot produce recycled water.

Generating Renewable Energy

VVWRA's generators that produce renewable energy, shown in Figure 1, are composed of two 800-kW 2G reciprocating engines. Together, they have the capacity to produce 1,600 kW, enough to produce power in excess of the WWTP's load at times. The generators are interconnected to the grid, enabling them to produce power on the same grid to which the WWTP is connected and with the same quality and characteristics as grid power, enabling it to be easily used by existing plant equipment.

Figure 1: Renewable Energy Generators

Two 800-kW renewable energy generators.

Source: Biogas Engineering

Rule 21 Agreements Affect Renewable Energy Generation

Energy projects that interconnect to the electric grid require a California Public Utilities Commission (CPUC) Rule 21 agreement, the terms of which can limit the amount of energy a project can produce. "Non-export" and "minimum export" agreements restrict the amount of power a project can generate and limit a project's ability to move California closer to its climate change goals.

The type of agreement that was available to VVWRA at the time the generators were installed was a minimum import agreement, which requires that the WWTP continuously import power from the utility; specifically, for this project, the WWTP must continuously import 80 kW of utility power. Importing less than 80 kW is known as a "minimum import violation."

Continuously importing at least 80 kW of utility power requires a delicate balance between the amount of power the WWTP produces and the amount of power it consumes — a balance that is difficult to achieve. The power consumed at the WWTP varies as systems change that either increase or decrease the plant load. These changes occur at rates faster than rates at which the generators can respond — that is, power being consumed by the WWTP changes faster than the power being generated by the WWTP. If that imbalance results in the WWTP consuming fewer than 80 kW, the generators are taken off-line.

The current method of avoiding minimum import violations is to consistently import about 200 kW of utility power. Standard WWTP process changes are not large enough to reduce the imported power below 80 kW if the WWTP is importing 200 kW. After a process change occurs, the generators ramp their production, either up or down, to import 200 kW of utility power.

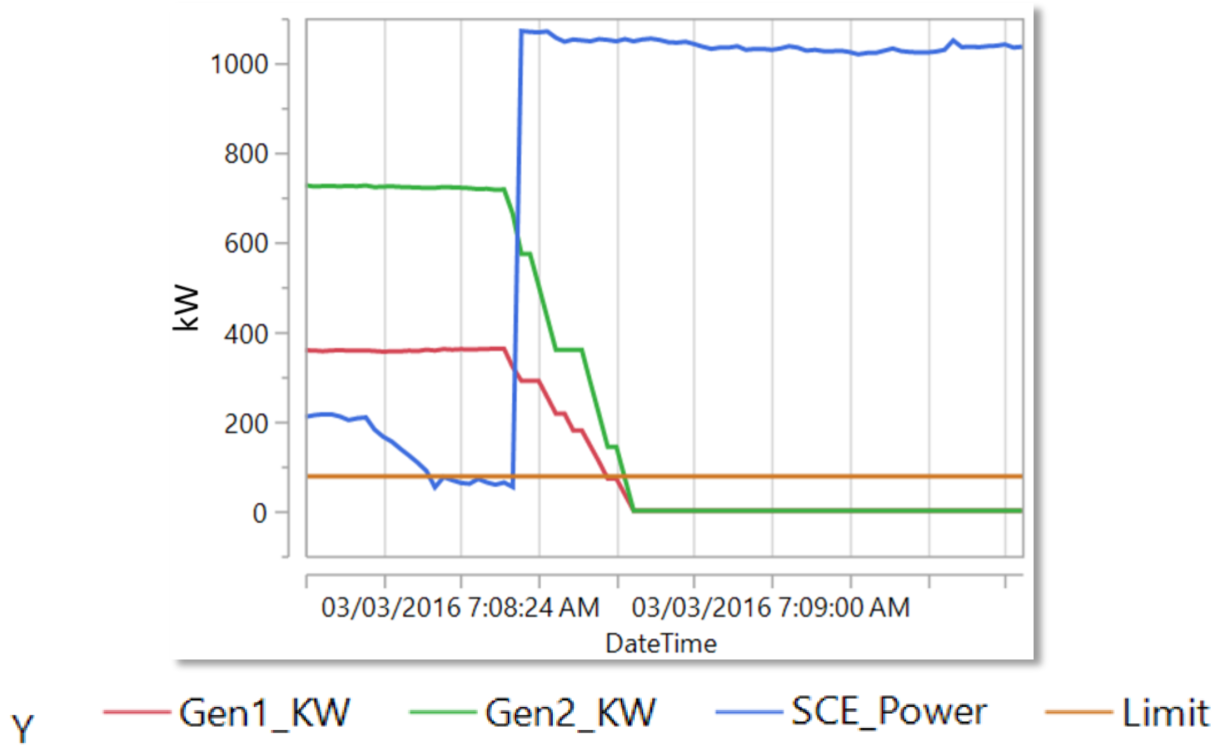
The system works reasonably well; however, there are drawbacks. For example, minimum import violations still occur, although much less frequently. Routinely importing 200 kW of utility power increases the amount of power the WWTP needs to purchase, resulting in higher energy costs for the plant. In addition, maintaining a utility import higher than necessary decreases the amount of renewable energy the WWTP produces and limits its ability to contribute to reaching California's climate change goals.

The Domino Effect of Minimum Import Violations

When a minimum import violation occurs, the generators are taken off-line. At that point, all the power and energy that the WWTP consumes is utility power, resulting in higher energy costs for the plant. Further, both renewable energy generation and recycled water production cease.

These events seem to correspond with the UV tripping. The UV is energy intensive with precisely measured components. It appeared that the near instantaneous change from receiving power that was self-generated to receiving power from the utility created momentary conditions that caused the UV to trip. Fluctuations in power quality seem to correlate with UV and generator shutdowns. Figure 2 below is a graphical illustration of a minimum import violation.

Figure 2: Minimum Import Violation



Southern California Edison power utility decreases below the minimum import threshold; both generators shut down; and utility power increases to satisfy full WWTP demand.

Source: Biogas Engineering

These power disturbances not only disrupt the renewable water system, they affect the entire wastewater treatment plant. Multiple pieces of equipment experience hard shutdowns that shorten the life of the equipment. Control devices for the plant, programmable logic controllers (PLCS), must be manually reset and verified, requiring extensive staff resources from both operators and control engineers. These disturbances also shut down the on-site power generation causing plant power to be provided by the utility. These effects reduce the plant's ability to generate renewable power and increase the load on the power grid.

Improving Power Management

Conditions of the minimum import agreement require close monitoring of power quality. The initial research was to focus on power disturbances to understand their characteristics so the power management system could most effectively address them. The researchers closely analyzed power quality at the site to understand the cause of the shutdowns and develop an EMS to improve the power quality. Initial analysis correlated quality events with minimum import violations. By coupling observed details of a significant number of recorded power disturbances with specific characteristics of the flow batteries, smart controller, and inverters, researchers could develop plans to anticipate and address quality events.

Accordingly, the project was designed using an advanced, pre-commercial energy storage system designed specifically to optimize on-site electricity consumption within the constraints of an 80-kW net power import agreement with the utility. Stored electricity would be released later, during variable load events, by an advanced controller system. In this way, the project would level existing variable loads, allowing the facility to consistently operate closer to the 80-kW level while making use of all renewable energy and avoiding shutdowns that currently interrupt water treatment and cause the wasting of effluent water.

Flow Batteries

Battery technology has existed for many years. Recent developments from companies like Tesla and applications such as cell phones have increased battery capacity while decreasing the size and weight of the batteries. These batteries overwhelmingly use solid-state lithium-ion technology. Solid-state lithium-ion technology is well suited for many applications; however, it has drawbacks that limit its applicability at wastewater treatment facilities. Solid-state lithium-ion batteries have a relatively short life span when compared to energy projects and have an inherent fire hazard.

Primus Power has developed an innovative hybrid flow battery system based on the zinc bromine chemistry called the EnergyPod. This hybrid flow battery system uses half the components of other flow battery designs. Also, the EnergyPod uses an electrochemical stack without any membranes or electrodes made of titanium metal. Membranes have proven problematic in other flow battery designs, and titanium is a relatively inexpensive material compared to the other electrode materials.

The EnergyPod's internal components are primarily made of low-cost, high-density polyethylene and are assembled with fewer components than traditional flow batteries. Fewer components enabled by creative design reduce production costs and maintenance and improve system reliability.

The Primus flow battery, Figure 3, is an energy storage technology developed with a longer lifespan than solid-state lithium-ion batteries. Primus flow batteries are sold with a 20-year warranty, whereas lithium-ion batteries begin to lose capacity within five to 10 years. The increased lifetime of the flow batteries makes it easier to secure financing for a public sector energy project. For which longer project lifetimes are required as payback periods in the four-to-five-year range are common.

Lithium-ion batteries also have an inherent fire danger. Some modes of failure for solid state lithium-ion batteries result in spontaneous fire and explosion. Wastewater treatment plants are essential facilities and generate methane in the form of digester gas as a component to their treatment process. Digester gas is flammable, and essential facilities are not likely to take on the added risk of the potential fire and explosion hazard that is included with lithium-ion batteries.

Figure 3: Primus Flow Battery

Primus Power EnergyPod2 flow battery installed at VVWRA.

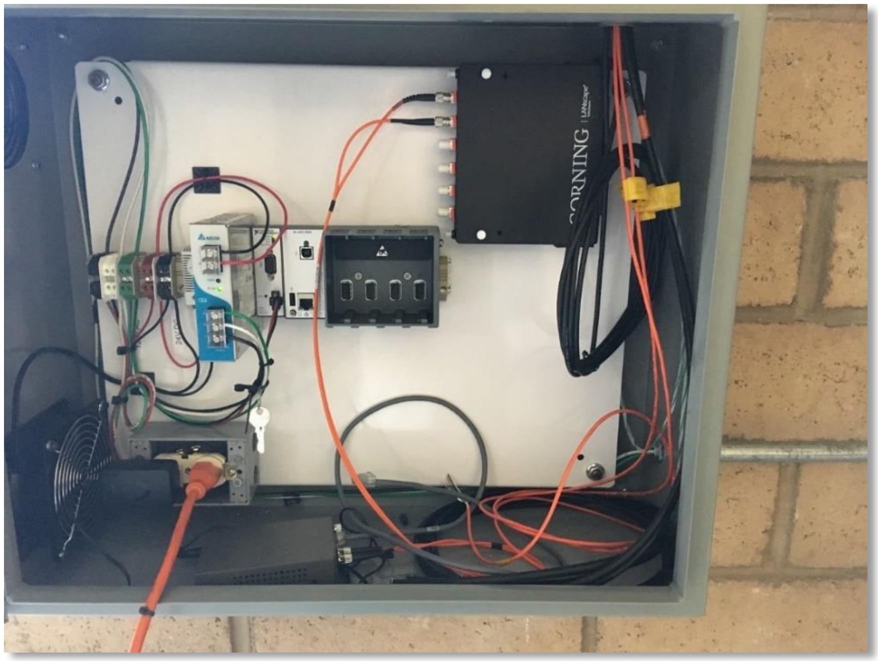
Source: Biogas Engineering

Smart Controllers

With the large increase in solar energy generation there has been an excess amount of power generated during the daylight hours and a large power demand in the early evening hours when the solar power has dissipated. Energy researchers have emphasized the development of energy management systems to store excess power not used during the day for uses in the early evening. Along with energy storage technologies, controllers to manage the varying power loads are being developed to meet these needs.

University of California at Riverside Center for Environmental Research and Technology (UCR CERT) is currently developing controllers known as "smart controllers" (Figure 4) to manage the balance between periods of higher generation and periods of higher consumption. This development emerged to support the solar power generation sector where predictable cycles of power generation and power consumption are more clearly known. The smart controllers use a hardware platform based on the LabVIEW programming language and can collect real-time utility power data, battery power data, and renewable energy generation power data. This data, coupled with custom programming to fit specific applications, is used to manage the generation and consumption of energy to achieve a desired outcome. Smart controllers appear to have potential application in other, non-solar based energy projects.

Figure 4: University of California, Riverside Smart Controller



University of California Riverside smart controller using a National Instruments controller and LabVIEW-based programming.

Source: Biogas Engineering

Project Goals

The goals of this project were to advance technologies that can increase the production of recycled water and increase the amount of renewable energy produced. The VVWRA WWTP has facilities that produce recycled water and renewable energy, and both are sensitive to power fluctuations. It was the goal of this project to build an EMS to reduce the power fluctuations caused by violations of the WWTPs minimum import interconnection agreement.

The flow batteries and smart controller were combined with the intent to manage the power generation and consumption profiles at VVWRA and reduce violations of the minimum import conditions, thus decreasing UV system and generator shutdowns, increasing production of recycled water and generation of renewable power, and decreasing the load on the grid. This, in turn, would allow staff more time for productive work and reduce the excess stress of hard shutdowns on the equipment, saving ratepayers money, and ultimately supporting and enhancing California's climate change goals.

CHAPTER 2: Project Approach

Existing Technology Characteristics

The first step in the approach to developing the project was to evaluate the characteristics of the current state of the technology and determine what modifications were required to fit the projects demands.

UCR Smart Controller

The University of California at Riverside (UCR) developed a smart controller for energy management in renewable energy systems. Most of the energy management applications to which the smart controller had been applied were designed to satisfy load shifting, peak shaving, frequency regulation, and electric reserve electricity capacity applications. The purpose of this project was to manage a dynamic power profile with energy storage and energy discharge with responses in less than one second to reduce the power buffer to near 80 kW and prevent minimum import violations.

To satisfy this demand, the data input to the controller would need to include data from the renewable energy generators, the imported power from the utility, and the state of charge of the batteries. The controller would need to monitor the utility-imported power and keep it at or close to the 80-kW limit by changing the power output of the generators and perform nearly instantaneous adjustments by storing or discharging power from the flow batteries.

Primus Flow Batteries

This project was designed to include two 100-kW/500-kWh zinc bromine flow battery systems. Unlike conventional flow batteries that use two flow loops (two tanks, two pumps) interacting across a set of membranes, the EnergyPod2 battery uses a single flow loop without membranes, which greatly reduces both system and operating costs and enables longer system life. There are also limits to the EnergyPod2 flow batteries that would need to be addressed.

The batteries require auxiliary power to power the pumps; the battery needs to be plugged in to be able to charge or discharge. These demands required additional electrical connections that increased the cost of construction. Also, the power requirements of the batteries slightly decrease the efficiency of the system, though this was minor. The main effect of the power requirement of the battery is that the site does not have very reliable power and routinely loses utility power. If utility power is lost, the batteries will not be able to discharge. Also, if utility power is not restored within two hours, the flow batteries would suffer permanent damage.

Another limitation of the batteries is that they need to be continuously either charging or discharging; they cannot hold static charge. The programming was adjusted so that half of the batteries would be discharging while the other half was charging.

Also, the batteries need to complete a refresh mode at least weekly but preferably daily. This refresh mode requires about one-and-a-half hours to complete and disables the batteries’ ability to participate in the control system during the refresh mode. Having batteries in the refresh mode would therefore decrease the capacity of the system.

Most importantly, the EnergyPod2 flow batteries were unavailable. The project was designed with eight battery pods; however, only two pods were delivered. Two battery pods do not have enough energy storage capacity to achieve the goals of the project.

2G Generators

The two 800-kW 2G generators generate grid quality power interconnected to the grid. The generators can operate at loads as low as 250 kW at steady state though their efficiency decreases at levels below their maximum 800 kW. The generators are interconnected to the WWTP control system and can ramp up or down at about the rate of 1 kw/second based on various inputs. This rate is not fast enough to respond to load changes that occur due to equipment shutting down. If a piece of process equipment at the WWTP turns off or trips, within seconds the import power to the WWTP will decrease based on the size of the equipment that turns off or trips. The loads of many pieces of equipment in the WWTP process are on the order of 100 to 200 kW. To avoid a violation of minimum import, the generators would need to reduce their load at a rate of about 100 or 200 kW/second. This limitation was to be addressed by the smart controller redirecting the energy into the flow batteries, effectively reducing the batteries' output until the generators could reduce their load to a level that would not violate the minimum import agreement.

Data Acquisition System

The WWTP has a data acquisition system known as a supervisory control and data acquisition system, or a SCADA system. The SCADA system receives and records data from all over the WWTP including the data necessary for the project's control system. The SCADA receives and records generator output from both generators and utility import data. The SCADA also can be programmed to deliver and receive data from the UCR smart controller and to receive data from the smart controller and the flow batteries.

Had the batteries arrived as scheduled and the full project been built and tested, the plant SCADA system would have been the location where all data from the project would have been sourced to generate performance reports and analysis.

Simulation Test

Before implementing the proposed control system, its effectiveness was tested in a simulation. Initially, the simulation was performed using MATLAB software and then later when LabVIEW programming was chosen for the project, a simulation with LabVIEW was performed.

MATLAB Simulation

MATLAB was initially chosen because it has several advantages over other methods or languages. Its basic data element is the matrix, and several mathematical operations that work on arrays or matrices are built in. It has vectorized operations that allow two arrays to be added together using only one command, and it can perform scientific calculations such as linear algebra. The graphical output of MATLAB is optimized for interaction. Data can be plotted and formatted easily. Its functionality can be greatly expanded by the addition of toolboxes, sets of specific functions that provided more specialized functionality. MATLAB allows for the testing of algorithms immediately without recompilation. Commands can be typed at the command line and the results can be immediately seen allowing for enhanced algorithm development. The MATLAB desktop environment allows interaction with the data and tracking of files and variables and simplifies common programming/debugging tasks. It can auto-generate C code, using the MATLAB coder, for a large (and growing) subset of image processing and mathematical functions. These mathematical functions could then be used in other environments, such as embedded systems or as a component in other software language.

MATLAB Simulation Environment Set Up

Setting up a MATLAB simulation requires generating the program, establishing a data recording system, and making some initial assumptions about the system at time zero. Table 1 includes the parameters that were implemented into the MATLAB simulation.

Table 1: MATLAB Simulation Parameters

Notation	State Parameters
fac_r	Facility load recording
fac_ind	Assumed facility load startindex
gen_ini	Assumed initial generators' output
gen_op	Simulated generators' output
sce	Simulated Southern California Edison output before battery response
sce_ini	Assumed Southern California Edison meter demand
sce_op	Simulated Southern California Edison output after battery response
Bat1_pv	Simulated Battery1 charging/discharging power
SOC1_ini	Assumed state of charge of the Battery 1 initial value
SOC1	Simulated state of charge of Battery 1
Bat2_pv	Simulated Battery2 charging/discharging power
SOC2_ini	Assumed state of charge of the Battery 2 initial value
SOC2	Simulated state of charge of Battery 2
soc_{upper}	Upper bound of the battery state of charge (75%)
soc_{lower}	Lower bound of the battery state of charge (25%)
soc_{lowest}	Lowest bound of the battery state of charge (1%)
stage1	Simulated Battery1 working stage
stage2	Simulated Battery2 working stage

Source: Biogas Engineering

MATLAB Simulation Results

In the MATLAB algorithm, the value that triggered the generators to reduce their output was between 100 kW and 120 kW. If import power exceeded 120 kW, the generators ramped up until import power reached between 100 kW and 120 kW. On the lower end, if import power dropped below 80 kW the controller commanded the battery to charge, redirecting generated power, until the utility input power increased to 95 kW. At 95 kW the battery charging decreased, and the generator ramp down continued until import power reached between 100 kW and 120 kW.

A few violations occurred during the simulation. One violation occurred because one of the batteries was in refresh mode and therefore temporarily removed from the control system. Another violation occurred because the power import level dropped an amount that exceeded the capacity of the batteries. Changes to the algorithm were made and violations decreased from six per month to two per month. The researchers concluded that this was an acceptable amount at which to consider implementing the algorithm.

LabVIEW with C_RIO Hardware Simulation

The researchers decided that LabVIEW with C_RIO hardware would be used in the smart controller because of its compatibility with the flow battery controls. The MATLAB algorithm then needed to be programmed into the LabVIEW hardware and tested.

LabVIEW programming offers advantages. It has a graphical user interface that is commonly used by design professionals. Design professionals use the drag-and-drop user interface library by interactively customizing the hundreds of built-in user objects on the controls panel. A programmer can then run modular LabVIEW virtual instruments (VIs) by themselves or as sub VIs and easily scale and modularize programs depending on the application. It has a compiled language for fast execution. The compiled language generates optimized code with execution speeds comparable to compiled C and code with high performance. LabVIEW can easily manage multiple targets, from real time to embedded devices including field programmable gate arrays (FPGAs), microprocessors, microcontrollers, personal digital assistants, and touch panels. LabVIEW has multiple high-level development tools that allow it to develop faster with application-specific development tools, including the LabVIEW Control Design and Simulation Module, LabVIEW FPGA Module, and LabVIEW Real-time Module. The programmer creates virtual instruments on an open framework that seamlessly integrates software and hardware. This allows applications to be easily integrated into new technologies in the future. There are libraries for integrating stand-alone instruments, data acquisition devices, motion control and vision products, general purpose interface bus/Institute of Electrical and Electronics Engineers 488 (GPIB/IEEE 488) and serial/recommended standard (RS)-232 devices, and PLCs to build a complete measurement and automation solution. Plug-and-play instrument drivers access the industry’s largest source of instrument drivers with several instruments from various vendors.

LabVIEW Simulation Environment Set Up

To run the simulation in LabVIEW, three items had to be completed. One, a personal computer (PC) had to be added that would contain historical site data to be used as the values determined for time 0. Two, an input/output (I/O) server based on LabVIEW’s Real-time Module had to be established to simulate the communication channels of a real system. The historical data in the PC was set as I/O server master port, and compact reconfigurable input/output (c-RIO) controller device acted as slave port. And finally, the control algorithm had to be programmed into the c-RIO controller device.

LabVIEW Simulation Results

The algorithm had already been verified in the MATLAB simulation, but the operability in LabVIEW c-RIO system had to be verified. The simulation indicated that the operability in the LabVIEW C-RIO system would be adequate.

Power Quality Events

With the hardware of the system understood and the controller developed, the next step was to investigate the details of the power events. Details of the power quality events, some of which were thought to be caused by minimum import violations, were analyzed to better understand the surrounding circumstances and the timeline between relative events.

Approach to Investigating Power Quality Events

Researchers used four monitoring systems to detect and analyze the power events. Every time a power event occurred at the WWTP that caused either the generator or the UV system to shut down, operators logged the date and time in a logbook and noted any other notable characteristics of the event. For each of these events, there were three separate digital data collection systems: two power monitors and the plant SCADA system. In 2016 there were 96 such occurrences that were investigated using all four sources of information.

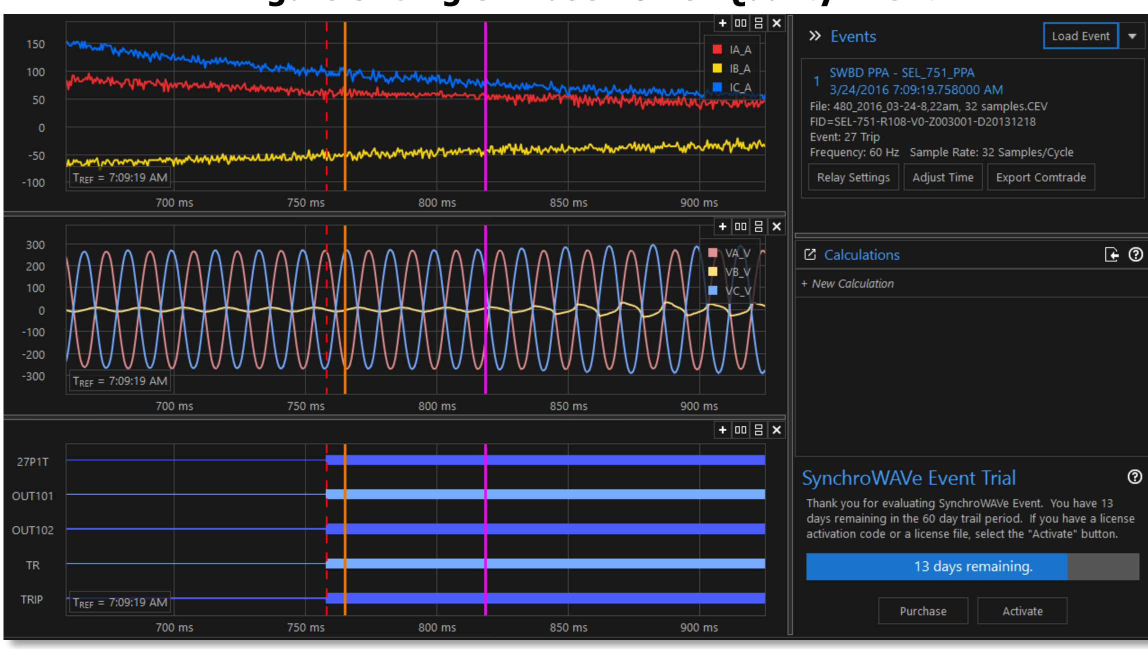
For each event, reports were pulled from the power monitors, if available, and data was downloaded from the SCADA system. The power monitors were installed as part of the renewable energy generators interconnection to the grid. The power monitors measured the three-phase power quality and the amount of import power to the WWTP to detect the minimum import violations.

Using all the data available from the four sources of information, different types of conditions were discovered that caused the generators and the UV system to trip.

Single-Phase Events

The power being delivered to the WWTP is three-phase power. After reviewing the reports from the power quality meters, it was observed that many of the events that caused the generators and the UV system to trip involved only one of the three phases. Figure 5 is an example of a single-phase power quality event that caused both the UV system and the generators to trip.

Figure 5: Single-Phase Power Quality Event



An undervoltage in one of the three phases.

Source: Biogas Engineering

Two-Phase Events

Some of the events detected involved two of the three phases. Figure 6 is an example of a two-phase power quality event that caused both the UV system and the generators to trip.

Figure 6: Two-Phase Power Quality Event

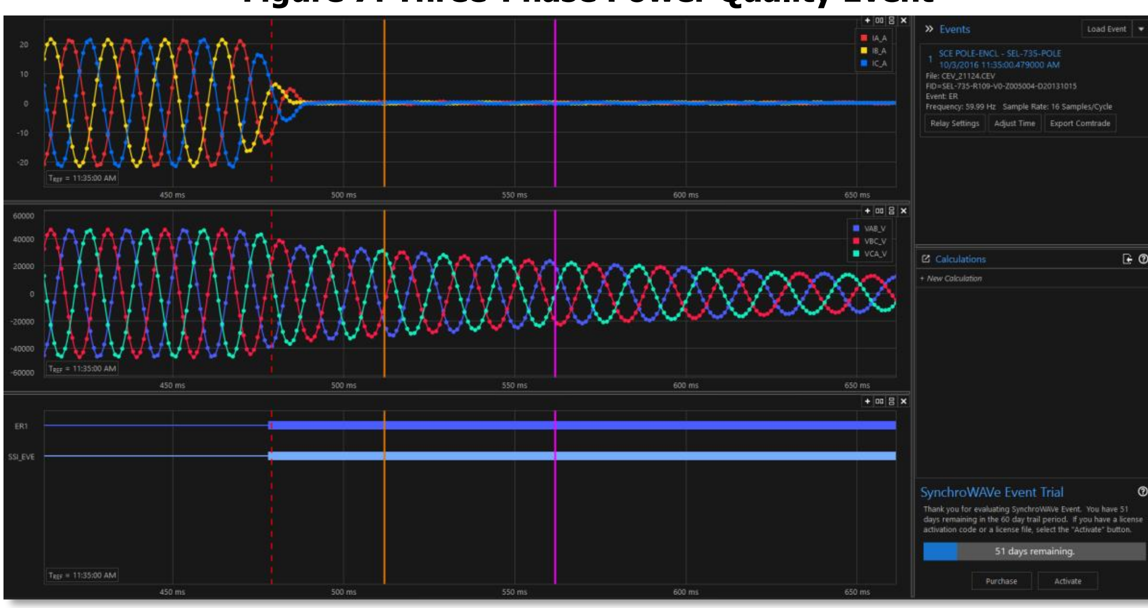
A voltage sag in two of the three phases.

Source: Biogas Engineering

Three-Phase Events

Some of the power quality events that caused the generators and the UV system to trip involved all three phases. Figure 7 is an example of a three-phase power quality event.

Figure 7: Three-Phase Power Quality Event



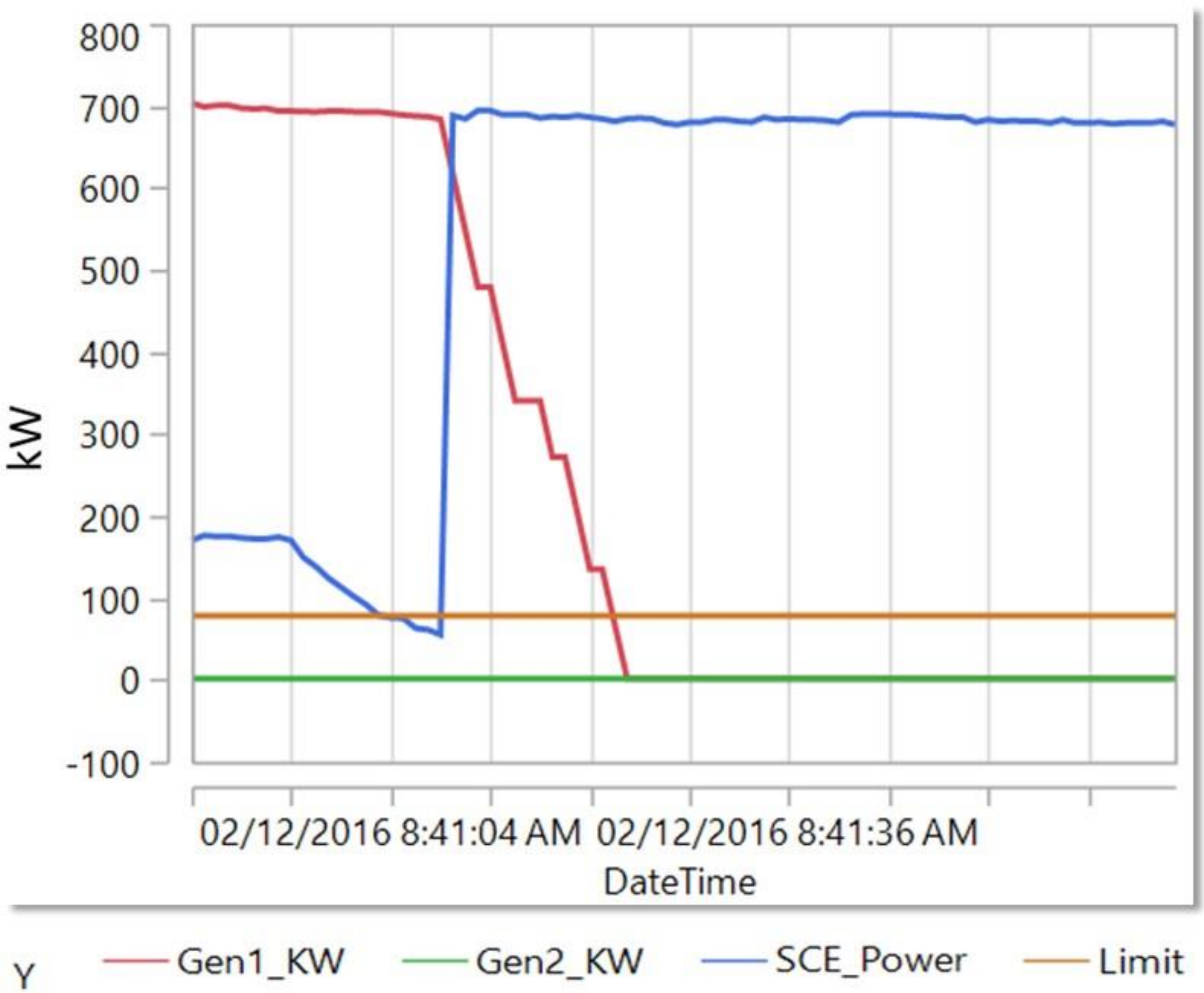
All three phases were affected during this power quality event.

Source: Biogas Engineering

Quality Events Involve Very Few Minimum Import Violations

Few of the events reported involved actual cases of minimum import violation, but some did. For these events, the power quality meter did not detect any power quality issues. The WWTP SCADA system was then consulted to monitor the quantity of power at the time of the occurrence. Figure 8 is graphical data from SCADA that indicates an actual minimum import violation.

Figure 8: Minimum Import Violation



Imported Southern California Edison power decreases below minimum import threshold causing the generator to be shut down.

Source: Biogas Engineering

Collaborating with the Utility to Resolve Quality Events

To enhance understanding of the power quality characteristics, the researchers held meetings with members of the utility and shared the reports.

The WWTP had been experiencing power outages and power quality issues for years. The utility was often notified of the events, but the power outages were often blamed on birds that were attracted to a neighboring composting site or to the location of the WWTP itself. The

WWTP was located at the end of a long distribution line, and it was often explained that power quality fluctuations were bound to occur in such a location.

The reports' findings demonstrated that many of the power quality events involved one or two phases of the three-phase power supply. These events could not be the result of minimum import violations and could not be addressed by the energy management system that was being installed. This development severely limited the ability of the project to affect recycled water production or recycled energy generation because the energy management system was designed to manage all three phases simultaneously, not individual phases.

Discussions with utility engineers about the reports and agreement with the details of the finding prompted the utility to offer more extensive support regarding power quality events at the site. Researchers and the utility discussed local infrastructure that could affect the power quality, and the utility conveyed settings on switches and power events at nearby facilities after the WWRP reported power quality events.

Collaboration Prompts New Interconnection Agreement

As the utility's understanding of the nature of the power quality events became clearer in discussions about the reports, the utility recognized that the addition of battery pods to the system would constitute an increase in system capacity and would also require a new interconnection agreement.

The utility recommended the VVWRA apply for a newly developed interconnection agreement, the Net Energy Metering agreement, known as NEM 2.0, that would remove the minimum import requirement. When VVWRA initially installed the renewable energy generators, an NEM interconnection agreement was not an option the utility presented. NEM interconnection agreements had been overhauled recently in response to the increase in solar energy projects. Under the new NEM 2.0, the VVWRA's renewable energy generators are eligible to participate. Removing the minimum import requirement would enable the WWTP to reduce generator shutdowns and increase renewable power generation.

Energy Management System Modification

With the renewable energy generators now having the ability to export power, avoiding violations of minimum import ceased to be a priority. However, the researchers were still intent on demonstrating an energy management system based on flow battery energy storage and a smart controller.

Understanding that they had greater freedom developing the energy management system because minimum import violations would no longer be possible, the researchers could take more risks regarding aggressive settings or controller tuning without penalty of generator shutdown. They decided creating and tuning the energy management system could be pursued aggressively. Demonstrating the ability to manage renewable energy generation with power consumption to maximize renewable energy generation and minimize power disturbances remained the goal of the project.

System Installation

The energy management system was designed to include eight Primus Power energy pods, two inverters, and a control panel. The installation would require engineering design drawings, construction, and construction management.

Design

Engineering drawings were generated for electrical, civil, and structural. The electrical installation interconnected into the system through the same panel into which the renewable energy generators are tied. The site for the battery pods was selected adjacent to the renewable energy generators and a structural foundation was designed to support the weight of eight Primus Power flow batteries.

The installation location for the UCR controller and the inverters was chosen based on the environmental requirements of the components. An adjacent building was repurposed to house both inverters and, in a separate room, the controller. The room with the controller was selected as the control room for the energy management system.

The flow batteries were designed to be installed in two sets of four with each set of four tied into one inverter. In this arrangement, one EnergyPod from each group of four would be the master. Only the master would be connected directly to an inverter; the other three in the set would be connected to each other and then to the master in a daisy chain arrangement.

Communication for the system would be achieved with shielded CAT5 cable, and data transmission into the plant SCADA system would be achieved with fiber optic cable terminated with Ethernet RJ-45 converters. Remote access would be available to the controller through an internet porthole that would allow communication, control, and data download from remote locations as well as directly from the on-site control room.

Delays in Primus Power delivery of the EnergyPod prompted the UCR design team to visit the Primus Power manufacturing facility to initiate testing. The site visits proved beneficial, as many issues with communication and controls were detected. One of the items that resolved many of the issues was to integrate Primus Power controllers known as PEMS (power energy management system) into the system. One PEMS unit would be installed to communicate to one inverter and one set of four flow batteries. The smart controller would then communicate to the inverters and the flow batteries through the PEMS units. The PEMS units would be installed in the control room adjacent to the smart controller.

Construction

Construction for the project began on February 8, 2018, and it took two months to complete most of the work. The site area had to be cleared of existing obsolete equipment before the ground could be prepared for the foundation installation. The conduit was placed below grade at the foundation. Conduit was delivered to the adjacent control room and the room that would house the inverters. After the conduit was set, the structural steel was placed, and the structural concrete was poured.

Figure 9 shows the completed foundation.

Figure 9: Prepared Flow Battery Foundation

Foundation for eight flow batteries and electric distribution. The building that houses the inverters and the control room is on the left.

Source: Biogas Engineering

Conduit was run between the EMS and the renewable energy generator control panel. The conduits allow for the transfer of energy between the EMS and the renewable energy generators (Figure 10). The conduit run was complicated because of the amount of below-grade infrastructure. Multiple conduit banks and piping had to be avoided.

Figure 10: Conduit Connection Between Energy Management System and Renewable Energy Generators

Conduit for power and controls to distribution Panel.

Source: Biogas Engineering

The inverters were delivered and set in the adjacent building (Figure 11). Some preparation of the building was required.

Figure 11: Inverters

Two Socomec inverters installed indoors.

Source: Biogas Engineering

Primus Power notified VVWRA that the manufacturing schedule of the flow batteries was severely delayed. Primus Power proposed delivering two used and older model flow batteries that could be installed and used for system testing. On June 26, 2018, two used flow batteries were delivered to the site, Figure 12.

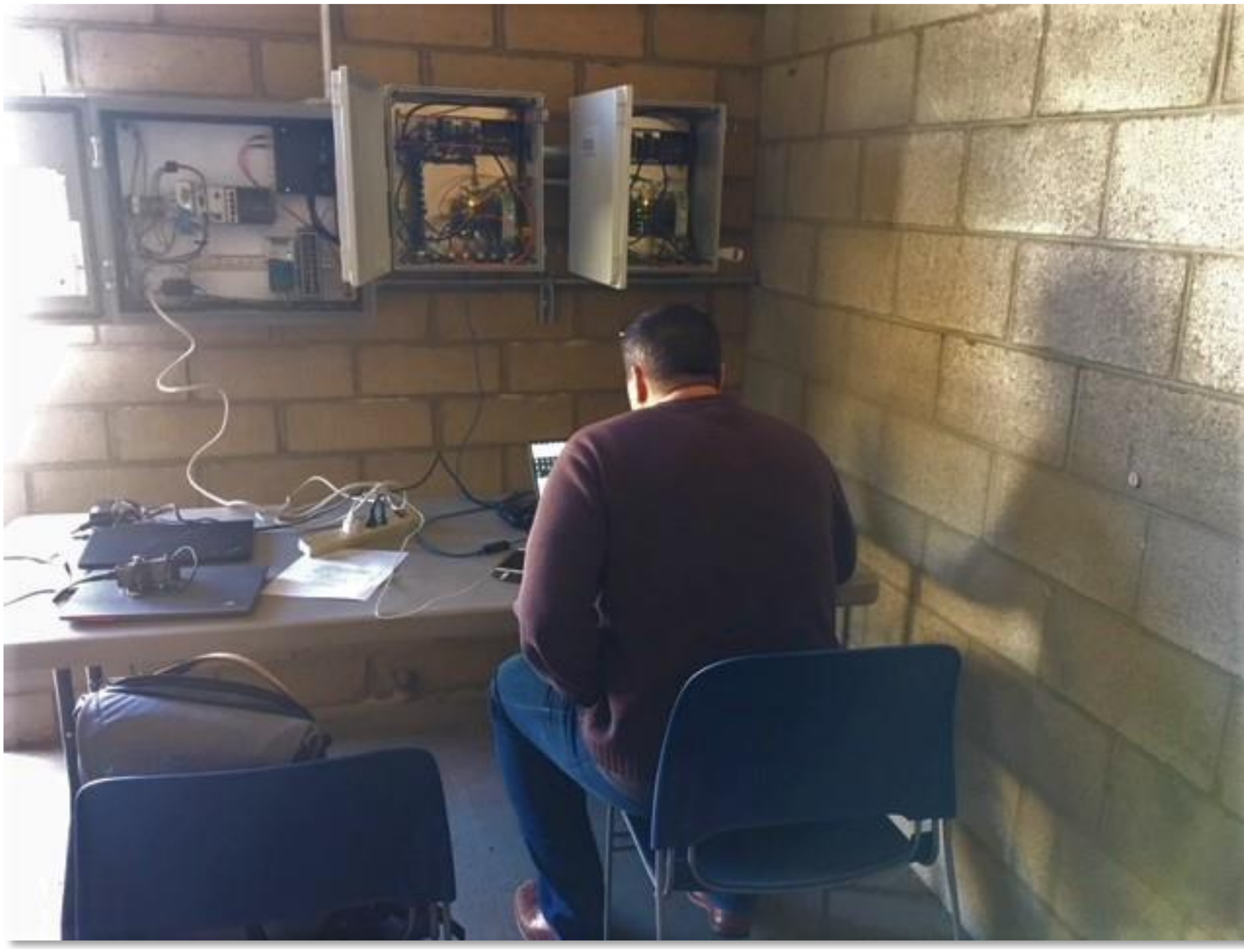
Figure 12: Two Flow Battery Test Units

The test flow batteries were installed as the two master units.

Source: Biogas Engineering

The controllers, smart controller, and two PEMS units were installed in the control room adjacent to the room with the inverters. The smart controller is composed of 24V and 48V DC power supplies, fiber optic data receiver, managed Ethernet switch, thermostat, and the National Instruments cRIO controller with accessory cards (Figure 13). The controller components are enclosed in a lockable metal cabinet to protect components from dust and for safety and security reasons.

Figure 13: Controllers



Smart controller on the left and two PEMS units.

Source: Biogas Engineering

Component Testing

The components of the EMS were installed per manufacturer's specifications and tested for proper operation. Primus tested the equipment it supplied: the inverters, flow batteries, and PEMS. UCR tested the smart controller.

System Testing

After each component was validated, the researchers began to test the entire system, issuing commands from the smart controller and monitoring the system's response. The initial testing intended to validate proper equipment operational status and data communication between devices. Later testing focused on system validation, commissioning, and startup.

The following processes were initiated through the smart controller LabVIEW program:

1. Start electrolyte flow on EnergyPod #1 and wait for temperature to reach operational range.
2. Start electrolyte flow on EnergyPod #5 and wait for temperature to reach operational range.
3. Test communication between PEMS #1 and UCR LabVIEW control program.
4. Test communication between PEMS #2 and UCR LabVIEW control program.

5. Charge EnergyPod #1 at maximum rate for one hour while recording battery parameters.
6. Charge EnergyPod #5 at maximum rate for one hour while recording battery parameters.
7. Discharge EnergyPod #1 at maximum recommended rate while recording battery parameters.
8. Discharge EnergyPod #5 at maximum recommended rate while recording battery parameters.
9. Perform refresh on EnergyPod #1.
10. Perform refresh on EnergyPod #5.

The researchers manually entered each command into the smart controller. Initial communication issues were resolved by upgrading the firmware on the PEMS units. The smart controller then communicated with both PEMS devices without any observed errors. Control commands were issued and received successfully from the smart controller through the PEMS units to inverters and flow batteries. One of the flow batteries, EnergyPod #5, showed limited power discharge capability. With only two flow batteries on site and one of the two compromised, further testing was halted to conserve resources for the arrival of the new flow batteries.

Failure of Primus Power to Deliver Flow Batteries

On September 27, 2018, Primus Power issued a letter stating that issues associated with manufacturing would delay the delivery of the eight flow batteries. Then, on May 20, 2019, Primus issued another statement reiterating the manufacturing issues and stating that the promised eight flow batteries would not be delivered; only two of the eight flow batteries would be delivered. With this information, the researchers compiled what information they had gained and developed a system startup test plan that could be used for the two flow batteries that would be delivered.

Startup Test Plan

The startup test plan that researchers developed tested individual components of the system, including the smart controller's communication interface, the read-only register, the read/write register test, the renewable energy generator control logic, and the smart controller logic.

Smart Controller Communication Interface Test

The communication between the smart controller and the system first had to be verified. The testing of the smart controller communication included the following steps:

1. Check ethernet switch configuration with all devices on local network.
2. Test communication between UCR controller and SEL-Axion.
3. Test communication between UCR controller and SCADA I/O server.
4. Test communication between UCR controller and Inverter 1.
5. Test communication between UCR controller and Inverter 2.
6. Test communication between UCR controller and Battery Management System (BMS) of Energy Pack 1.
7. Test communication between UCR controller and BMS of Energy Pack 2.

Read-Only Register Test

The read-only register is the component of the controller that receives and reads the data to which the controller is meant to respond. For this controller, the data in the read-only register is import power data, the state of the flow batteries and the renewable energy generators. The tests to be conducted for the read-only register included:

1. Read and log SCE active/reactive power data from SEL-Axion.
2. Determine SCE power data maximum refresh rate.
3. Read and log all facility data (Gen1, Gen2, and so on) from SCADA I/O server.
4. Read and log battery (BMS) parameters (status registers) warnings/alarms/faults.
5. Read and log inverter parameters and warnings/alarms/faults.

Read/Write Register Test

A read/write register, sometimes just called a register, is a fundamental type of shared data structure that stores a value and has two operations. The read operation returns the values that are stored in the register. The write operation updates the value stored. The test of the read/write register included the following steps.

1. Test read/write the registers for the battery (charge, discharge, refresh, and so on).
2. Test read/write the registers for the inverter (charge, discharge, active/reactive).
3. Test battery response time.
4. Test inverter response time.
5. Determine time delay from charge command sent to battery, to power change detected at power monitor.

Renewable Energy Generator Control Logic Test

The renewable energy generators were programmed to respond to import power. If the import power got too low, based on an inputted setpoint, the generators would ramp down. Vice versa, if the import power got too high, the generators would ramp down. The following is the list of tests to be conducted.

1. Test generator ramp up by setting the import trigger value with battery.
2. Test generator ramp down by setting import trigger value with battery.
3. Test generator steady output state.

Smart Controller Logic Test

The test of the smart controller included the following items:

1. Check whether the UCR controller prevents the violation of controller logic (anything below 180 kW)
    a) Test above logic with Battery 1 only.
    b) Test above logic with Battery 2 only.
    c) Test above condition with both batteries.
    d) Test above condition with different initial SOC conditions for Battery 1 and Battery 2.

2. Test controller response to alarm states.
    a) Alarms from SCADA (facility).
    b) Alarms from battery.
    c) Alarms from inverter.
3. Test refresh cycle for each battery.
    a) Frequency of refresh needed.
    b) Refresh time.
    c) Refresh power.

New Primus Power Flow Batteries

On October 19, 2019, Primus Power removed the used Flow Batteries and installed two new flow batteries. The flow batteries required commissioning that extended into March because of a failed component on one of the units. When commissioning was completed, the researchers had time to issue charge and discharge commands as the project came to an end.

CHAPTER 3: Project Results

The original goal for the project was to create an EMS that would mitigate power quality fluctuations experienced by the Victor Valley Water Reclamation Authority's wastewater treatment plant and thus increase the amount of recycled water produced and of renewable energy generated in service of California's climate change goal. Two unanticipated and extraneous events forced significant restructuring of the project. However, a third unanticipated revelation that was a function of original project specifications — analysis of the details of the quality events — resulted in project goals ultimately being met, though via different means.

Site Power Quality Improvement

One of the goals of the project was to reduce the number of shutdowns that the recycled water producing equipment was experiencing. The shutdowns seemed to correlate with minimum import violations because the generators were being shut down as well. Research determined that the shutdown events were mostly caused by power quality issues unrelated to minimum import violations.

Investigation of the power quality events generated graphical material to discuss with the utility. After these discussions, the utility increased their involvement in helping to resolve the issues. Local area infrastructure improvements were discussed along with offers to increase power monitoring. This resulted in added hardware and a reduction in power quality events.

Added Hardware

Adjacent to the WWTP is a composting facility that attracts birds, and birds contacting the power wires could have been the cause of some of the power quality events. In researchers' discussions with the utility, installation of hardware on the poles to protect the power wires from the birds was mentioned as an option to improve power quality. Other additional pieces of hardware known as line spacers that prevent the phases from making contact have since been added onto the surrounding power wires. These are shown in Figure 14.

Figure 14: Line Spacers on Utility Wires

Line spacers added to utility wires just outside VVWRA WWTP.

Source: Biogas Engineering

Reduced Site Blackouts

Momentary events of poor power quality at the site caused multiple shutdowns and equipment failures at the site. In 2016 at least 96 events that caused momentary power outages were recorded. These shutdowns had a negative effect on plant operations and plant equipment and decreased the amount of recycled water produced. Since the beginning of this project, the number of shutdowns has decreased by 70 percent.

Reduced Shutdown of Recycled Water Producing Equipment

The reduced number of power outages at the WWTP has resulted in a reduced number of shutdowns of the UV system. This reduction in shutdowns allows for more water to be treated with the UV system to create recycled water that meets Title 22 standards.

New Interconnection Agreement Increases Renewable Energy Production

Another project goal was to increase the amount of renewable energy produced at the site. This originally was going to be achieved by reducing the number of minimum import violations and enabling operations closer to the minimum import limit with improved power management. However, two events scuttled this plan. First, the manufacturer’s inability to deliver a sufficient number of flow batteries to have the capacity for an energy management system meant that the system could not be built. In addition, researchers' thorough observation and analysis of the quality events that caused production shutdowns demonstrated that the shutdowns were not a function of minimum import violations, but rather of utility-related issues beyond VVWRA's control. This information prompted discussions with the utility, which initiated several remedies, including the recommendation that VVWRA apply for an NEM 2.0 — a net energy metering interconnection agreement recently developed that was not available when VVWRA installed its generators and that would eliminate minimum import requirements, thus enabling VVWRA to increase its renewable energy production.

University of California, Riverside Smart Controller

The researchers built a smart controller designed to manage power profiles to address a specific problem, minimum import violation. The smart controller was designed to receive utility data and control generator output and operate the flow batteries to enhance energy management at the WWTP.

The researchers programmed the controller and tested the logic with a simulation, first in a MATLAB platform and then in LabView, simulating battery operation and generator power output. From evaluating early simulation results, the researchers were able to tune the logic for improved performance in the simulations. They were also able to detect limitations of the flow batteries, specifically the required refresh mode. Because an adequate number of flow batteries was never delivered, they were unable to test the smart controller in a field test.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

Partnering with the University of California at Riverside Center for Environmental Research and Technology (UCR CE-CERT) provided opportunities to present the project at several industry events.

Conferences

- 2018 UCR Solar Energy Conference, Riverside, California, March 1, 2018: For the first presentation of the project, researchers presented a poster describing VVWRA's operations and its goals for the project. The poster included profiles of the power generated by the 2G system and the SCE imported power, as well as the smart battery controller architecture, control scheme, and simulation work.
    - Xue, Y., Todd, M., Ula, S., & Martinez-Morales, A. A. (2018). Victor Valley Wastewater Reclamation Authority *Water Optimization and Energy Efficiency Project*. 2018 UCR Solar Energy Conference. Riverside, California, March 1, 2018.
- 2019 UCR Solar Energy Conference, Riverside, California, February 28, 2019: A poster presentation included a graphical introduction of the energy profile the project is designed to manage, including details of the battery charge and discharge profile and how they would be integrated into the power profile at the site for power management.
    - Xin, H., Penchev, M., Xue, Y., & Martinez-Morales, A. A. (2019). *Utilizing Zinc Bromine Flow Battery to Prevent Minimum Import Violation*. 2019 UCR Solar Energy Conference. Riverside, California, February 28, 2019
- International Association of Science and Technology for Development (IASTED) International Conference on Control and Optimization of Renewable Energy Systems, Anaheim, California, Dec 6–7, 2019: In a presentation, researchers discussed the flow battery characteristics, the control method, and the simulations that were run to test the controller. A published paper resulting from the presentation describes the use of the flow battery in an energy management system to support projects with minimum import requirements.
    - Xin, H., Penchev, M., Xue, Y., & Martinez-Morales, A. A. (2019). Rule-Based Real-Time Control of A Flow Battery for Preventing Minimum Import Violation. Control and Optimization of Renewable Energy Systems / 860: *Mechatronics and Control*. doi:10.2316/p.2019.859-025

Symposium

Alfredo A. Martinez-Morales, Ph.D., of UCR, presented "Demonstration of Flow Batteries for the Prevention of Minimum Import Violations" at the 2018 UC Solar Research Symposium in San Francisco, California in October. The presentation addressed the worldwide increase in the deployment of electrochemical storage and the role that a zinc bromine flow battery can play in this deployment. It included illustrations of the power profile at VVWRA and the role that the Primus Power battery system can play in energy storage and power management.

Workshop

Logan Olds, VVWRA's general manager at the time, presented "VVWRA Renewable Energy Storage and Increased Recycled Water Production Project" at the 2019 UCR Water, Energy, and Policy Workshop in Riverside, California, February 27, 2019. The presentation provided details of the power system at VVWRA, including the fuel conditioning system, the 2G power generation system, power profiles for the site, and technical details of the power quality issues the project was designed to address.

Target Market

The anticipated target audiences for the technology are municipalities and private industries that use self-generation. The proposed technology would have been applicable to all industrial facilities with self-generation that operate under no-export or net import agreements with utilities.

The near-term markets for the technology are municipalities with self-generation. After the technology has been successfully demonstrated on multiple projects, the private sector with goals of reducing long-term energy costs will begin to experiment with the technology.

CHAPTER 5: Conclusions and Recommendations

Although researchers had to alter the execution of the project as originally planned, one of their original focus areas resulted in the project's success.

Careful analysis of the highly detailed power quality reports that the researchers and plant engineers generated revealed that the power quality events that had long plagued the VVWRA and forced shutdowns of production of recycled water and generation of renewable energy were not, in fact, a function of minimum import violations, but were a result of utility issues that were beyond the scope of the plant to correct. This revelation led to increased cooperation with utility staff, including the recommendation that the VVWRA obtain a new interconnection agreement that eliminated minimum import requirements, thereby freeing the VVWRA to increase its production of recycled water and generation of renewable energy.

CHAPTER 6: Benefits to Ratepayers

Improved Local Power Quality and Enhanced Interconnection Increase Renewable Power Generation

Poor local power quality has negative impacts on homes, businesses, and essential facilities that serve our communities. In this project, researchers investigated power quality. Sharing their surprise findings with the local utility, Southern California Edison, resulted in the utility's implementation of system improvements that improved power quality and reduced shutdowns at the wastewater treatment plant by 70 percent from 2016 to 2019.

Again, as a function of the researchers' investigation of power quality, the utility required a new interconnection agreement with Victor Valley Water Reclamation Authority that allows for increased generation of renewable energy and greater export of power to the grid. Increases in renewable energy production will both help California satisfy its climate change goals and reduce demand on the grid. The reduced shutdowns at the plant and subsequent consistent and more prolific production of recycled water will also further California's climate change goals and decrease demand on an already-limited water supply.

Finally, the reduction of system shutdowns decreased the extra workload placed on operations and information technology staff, controls engineers, instrumentation technicians, and management to reset and verify all related systems and corresponding equipment, instrumentation, and programmable logic controllers. Shutdown reductions also reduce wear and tear on the equipment.

LIST OF ACRONYMS

Term	Definition
BMS	Battery Management System
CPUC	California Public Utilities Commission
c-RIO	compact reconfigurable input/output (controller device)
EMS	energy management system
FPGA	field programmable gate array
I/O	input/output
kW	kilowatt
PEMS	power energy management system
PLC	programmable logic controller
PC	personal computer
SCADA	supervisory control and data acquisition system
SCE	Southern California Edison
SOC	state of charge
UCR CE-CERT	University of California at Riverside Center for Environmental Research and Technology
UV	ultraviolet
VI	virtual instrument (as in LabVIEW virtual instrument)
VVWRA	Victor Valley Wastewater Reclamation Authority
WWTP	wastewater treatment plant